



**Report to the
National Radio Systems Committee**

**FM IBOC DAB Laboratory
and Field Testing**

August 2001

iBiquity Digital Corporation

**8865 Stanford Boulevard, Suite 202
Columbia, Maryland 21045
(410) 872-1530**

**20 Independence Boulevard
Warren, New Jersey 07059
(908) 580-7000**

Executive Summary

iBiquity Digital Corporation's report to the National Radio Systems Committee details results of laboratory and field tests of its FM IBOC DAB system. These test results demonstrate conclusively that iBiquity's system represents a significant improvement over existing analog service and that IBOC can be introduced without meaningful interference to existing analog operations. The information in this report supports the conclusion that IBOC meets the needs of the broadcast industry, the consumer electronics industry and the listening public. iBiquity encourages the NRSC to promptly endorse the IBOC DAB system to encourage the rapid commercial rollout of digital radio next year.

The test program summarized in this report was conducted in accordance with the NRSC's IBOC DAB test procedures. The tests included both laboratory and field tests designed to assess the performance of the digital system and to determine whether digital implementation would impact existing analog operations. Objective laboratory tests were conducted by the Advanced Television Testing Center. Field tests were conducted by iBiquity personnel in the presence of NRSC observers. Audio samples from the field and the laboratory were subjectively evaluated at Dynastat Laboratories. Additionally, iBiquity has completed detailed station, market and listener analyses and extensive field trials to quantify the potential real world impact of digital interference on the existing FM broadcast infrastructure.

The performance test results provide an overwhelming endorsement of the benefits of IBOC. For every evaluation criteria the NRSC has adopted, IBOC's performance is superior to or, at a minimum, equivalent to analog. Similarly, the overall compatibility results confirm IBOC will not degrade analog performance. An overview of iBiquity's results addressing the evaluation criteria is outlined below.

Audio Quality

The performance tests establish the superiority of IBOC audio quality when compared to analog. In performance tests involving 600 sound samples and 120 listeners, evaluators overwhelming and consistently scored IBOC superior to analog. This superiority of IBOC performance applies in all tested genres including classical, country, rock, speech, and voiceovers. Moreover, these test results were obtained in all significant test conditions such as multipath interference, first adjacent, second adjacent and dual interferers, noise and impairments. iBiquity believes these results were based on the improved audio quality of the IBOC system and the system's ability to improve the overall listening experience.

Service Area

Field tests conducted on eight FM stations representing all station classes and conditions demonstrated the extensive service area IBOC provides. Even at 1/100 of the power of analog, IBOC provided high quality audio throughout the existing market. Overall, digital coverage consistently extended to at least the 45-50 dBu signal level. In several cases, digital coverage extended well beyond this to the 15-25 dBu signal level. In all cases, the system's blend-to-analog feature ensured that coverage was never less than existing analog coverage.

The test results show this level of digital coverage with first adjacent and second adjacent channel interference, multipath terrain obstructions, multiple classes of stations and various antenna configurations. The field tests demonstrated flawless digital coverage throughout Manhattan where multipath significantly degrades analog reception. In San Francisco, the test results show the digital system's extensive coverage in one of the most challenging environments for analog FM. Moreover, the system has shown its ability to withstand extreme levels of adjacent channel interference. In field tests conducted on WHFS, the IBOC system delivered digital coverage with second adjacent interference of -65 dBu D/U.

Durability

IBOC also exhibited superior robustness in the face of interference and channel impairments. Subjective evaluations of audio samples from digital and analog auto receivers resulted in consistently higher scores for digital performance with first adjacent channel interference, second adjacent channel interference and multipath. Throughout these tests, digital performance remained consistently strong even as impairments increase. This contrasts with analog performance, which degrades progressively as impairments become more severe. The introduction of digital will increase resistance to interference and transform areas of unacceptable analog performance into areas with excellent digital quality.

iBiquity designed an additional robustness test, the "Ticker Test," which was used to evaluate impairments on audio samples for both digital and analog receivers. Evaluators found that the analog samples had 4-5 times more impairments than digital. Even more importantly, participants reported hearing 6-7 times more severe analog impairments than digital. The listeners' subjective evaluation scores also demonstrated that the quality of the audio was directly related to the number of impairments. Therefore, IBOC's elimination of impairments resulted in a marked improvement in digital quality and digital durability.

Host Compatibility

The test program confirmed the IBOC system caused no harm to the analog operations of the host station. The newly introduced digital signal did not degrade the analog operation of the same station. An analysis of the subjective evaluation of audio samples with IBOC turned off and on indicated listeners did not perceive any meaningful difference from the introduction of IBOC.

First Adjacent Compatibility

Examining the full test record leads to a definitive conclusion: the introduction of IBOC will have no meaningful impact on FM analog broadcasting from increased first adjacent interference. Although field test results indicate some potential impact on analog first adjacents, further analysis of the real world situation demonstrates that the incidence of this potential impact is not meaningful. Detailed analysis of every FM station across the country shows that the actual coverage area potentially impacted by IBOC first adjacent interference is very small. Further, analysis of existing listening patterns demonstrates that within the limited area potentially affected, the number of existing listeners is exceedingly small. On average, only 0.6% of an FM station's existing analog listeners will experience any impact from the introduction of IBOC. This analysis is supported by iBiquity's extensive field trial record. Over the past 24 months of on-air trials, iBiquity has broadcast IBOC on commercial stations in some of the nation's most interference intensive markets without any reported impact to the analog broadcasts.

Second Adjacent Compatibility

Results of second adjacent compatibility tests mirror the host compatibility results. Again, evaluators indicated no meaningful difference in the analog signal with the digital turned off or on. In the case of portable and home Hi-Fi receivers, the impact of IBOC at stronger interference levels only occurs when analog second adjacent interference has already severely degraded the desired analog signal. At that point, the digital signal's impact is irrelevant.

...

The test results provide a comprehensive view of the benefits of IBOC. The digital system has the potential to offer significant upgrades and benefits without harming analog operations. iBiquity encourages the NRSC promptly to endorse IBOC and move forward to promote industry implementation of digital radio early next year.

TABLE OF CONTENTS

TABLE OF CONTENTS

Executive Summary	i
Audio Quality	i
Service Area	ii
Durability	ii
Host Compatibility	iii
First Adjacent Compatibility	iii
Second Adjacent Compatibility	iii
I. Introduction	2
A. Background on iBiquity and IBOC Technology	2
B. The NRSC Test Program	2
C. Subjective Component of NRSC Test Program	5
D. Value of Field Test Results	6
E. The Test Report	7
II. Results	8
A. Audio Quality	8
B. Service Area	9
1. Overall Coverage	10
2. Coverage with First Adjacent Channel Analog Interference	12
3. Coverage with Second Adjacent Channel Analog Interference	13
4. Coverage with Second Adjacent Channel Digital Interference	15
5. Coverage with Dual Second Adjacent Channel Analog Interferers	15
6. Coverage with Multipath	17
7. Coverage for a Class A Facility	21
8. Coverage with Multiple Antenna Configurations	22
9. Coverage with Terrain Obstructions	22
C. Durability	27
1. Subjective Evaluation of Field Audio Samples	28
2. Ticker Test	32
D. Acquisition Performance	35
E. Auxiliary Data Capacity	35
Hybrid	36
Extended Hybrid	36
All Digital	36
F. Behavior as Signal Degrades	37
G. Stereo Separation	38
H. Flexibility	39
I. Host Compatibility	39
J. Non-Host Compatibility	40
1. First Adjacent Compatibility	40
2. Second Adjacent Compatibility	53
III. Conclusions	55

This report to the National Radio Systems Committee ("NRSC") details the results of laboratory and field tests of iBiquity Digital Corporation's ("iBiquity") FM IBOC DAB system. During the past seven months, iBiquity's system has undergone comprehensive tests carried out pursuant to laboratory and field test procedures the NRSC developed. The results described in this report demonstrate that the iBiquity™ FM IBOC DAB system represents a significant improvement over existing analog service and that IBOC can be introduced without meaningful interference to existing analog operations. iBiquity has demonstrated through this test program, carried out by independent third parties, that its system can provide robust digital performance throughout the market served by today's analog stations. The tests also show the iBiquity system eliminates virtually all of the impairments that degrade existing analog broadcasting and, at the same time, demonstrate that the system offers higher audio fidelity. These improvements can be introduced without meaningful interference to existing analog stations. The information in this report supports the conclusion that IBOC meets the needs of the broadcast industry, the consumer electronics industry and the listening public and should be implemented in the United States. iBiquity encourages the NRSC to endorse iBiquity's IBOC DAB system, to provide a written endorsement of IBOC to the Federal Communications Commission and to promote the rapid commercial rollout of digital radio to meet the needs of listeners, broadcasters and the consumer electronics industry.

I. Introduction

A. Background on iBiquity and IBOC Technology

iBiquity was formed in August 2000 through the merger of Lucent Digital Radio and USA Digital Radio. iBiquity is the world's leading developer of digital technology for terrestrial radio broadcasting and is at the forefront of innovation and development in the field of audio compression. iBiquity is owned by a broad coalition of broadcasters, transmitter, semiconductor and receiver manufacturers and leading financial institutions that have come together to support the transition of AM and FM radio from analog to digital. Among iBiquity's broadcast owners are fourteen of the nation's top twenty radio broadcasters, including the eight largest. Together, these companies operate more than 2300 radio stations in the United States in over 239 of the 283 Arbitron-rated markets. iBiquity's owners have access to over 220 million listeners and account for 57% of the broadcast industry's annual revenues. iBiquity's owners also include the nation's largest transmitter manufacturer and second largest radio receiver manufacturer. Additional information about iBiquity can be found at its web site: www.ibiquity.com

iBiquity and its predecessors pioneered the development of digital technology for terrestrial AM and FM broadcasting. The iBiquity technology focuses on a digital solution that works within the existing broadcasting infrastructure and also provides key benefits for broadcasters, consumers, equipment manufacturers and regulators. This system places the digital signal within the existing spectral emissions mask for analog AM and FM broadcasts. As a result, IBOC will be introduced without the need for new frequency allocations and without disruption to the existing broadcasting infrastructure.

Broadcasters will be able to use their existing transmission facilities and studio equipment with only the addition of an IBOC exciter and, in limited cases, an upgrade to the station transmitter. Moreover, IBOC has the important advantage of offering all broadcasters the ability to upgrade to digital. The IBOC approach also benefits consumers by permitting the provision of digital service without changes in consumer behavior. They will continue to tune to the same dial position to find their favorite stations. Finally, IBOC will allow regulators to authorize the introduction of DAB without the need to identify new spectrum or issue new licenses. Overall, the result will be much more prompt introduction of service than could be achieved with a non-IBOC approach.

IBOC technology offers the public an improved listening experience and allows broadcasters to offer new services to listeners. IBOC provides improved audio fidelity and enhanced robustness to the broadcast signal, even in the presence of impairments and interference. Additionally, IBOC permits the introduction of new data services to consumers to complement existing audio programming. iBiquity has structured its system to maximize the benefits to consumers within the constraint imposed by the need to protect existing analog AM and FM services. Importantly, the system has been designed to afford broadcasters considerable flexibility to tailor the system attributes to meet the specific needs of listeners in particular markets.

The iBiquity FM system presented in this report is based on the LDR and USADR systems that were tested in 1999 and evaluated by the NRSC in 2000. The general system characteristics and attributes are well known by the NRSC. Due to marketplace demands for rapid testing and implementation of IBOC and equipment constraints, the system tested and presented in this report used AAC as audio compression technology. iBiquity will use iBiquity's audio compression technology in commercial IBOC equipment. This substitution of the system codec will not impact any of the test results presented in this report. It also is important to note that the results presented in this report, conducted with first generation equipment, represent a baseline for IBOC performance. Any subsequent changes in the system will be incorporated only to the extent that they improve system performance. Additionally, iBiquity anticipates commercial grade equipment will exhibit even better performance than the results presented herein. A detailed description of the system tested can be found in Appendix A. All results presented in this report were derived from operation of the IBOC system in the Hybrid waveform mode. No tests were performed using the Extended Hybrid or All Digital modes.

B. The NRSC Test Program

On August 14, 2000, the NRSC released a Request for Proposals offering all interested parties with functional IBOC DAB systems an opportunity to participate in the NRSC's standards development process. iBiquity is the only company that responded to the NRSC Request for Proposals. At the end of 2000, the NRSC developed comprehensive FM IBOC laboratory and field test procedures focused on two areas. First, the test procedures were designed to assess the performance of the iBiquity system

(i) in a clean channel environment, (ii) with various forms of impairments, (iii) with co- and adjacent channel interference, and (iv) with multipath interference. Second, the test procedures were designed to address the system's compatibility with existing analog operations by looking at any impact on host channel analog operations as well as analog first and second adjacent channel stations. Based on its analysis of market information, the NRSC selected the following four analog receivers for testing, representing commercially available and commonly used receivers in the most important market segments. These receivers also were selected for their ability to provide some of the best

Type	Manufacturer	Model No.
Original Equipment Auto	Delphi	PN 09394139
Aftermarket Auto	Pioneer	KEH-1900
Home Hi-Fi	Technics	SA-EX140
Portable	Sony	CFD-S22

Table 1 – List of Test Receivers

performance in their respective market segment. All four receivers were used for both performance and compatibility testing. In the performance tests, recordings were made of the digital and analog receivers. The analog receivers were used to provide an analog reference for comparison with digital performance. In compatibility testing, only the analog receivers were used. These tests were designed to compare the quality of the analog receiver with IBOC turned off and on. This comparison was meant to assist the NRSC to assess any impact of digital transmissions on the analog signal.

All objective laboratory tests were conducted at the Advanced Television Technology Center, Inc. ("ATTC") in Alexandria, Virginia using the IBOC DAB test bed established for the iBiquity system. ATTC is a private, non-profit corporation organized by the broadcast and consumer products industries to test digital broadcast systems. Appendix B contains a schematic of the ATTC test bed. The NRSC and its observers were afforded open access to the ATTC test bed at all times, and an NRSC representative actively participated in the lab's work. The ATTC recorded all data from these tests. Appendix C contains a report describing the procedures followed at the ATTC. The laboratory tests produced a series of objective measurements that are summarized in the ATTC's report contained in Appendix D. In addition to these objective measurements, the ATTC recorded audio samples for both the digital and analog receivers for each test conducted. The audio samples were subsequently sent to Dynastat, Inc. in Austin, Texas for subjective evaluation. Dynastat's laboratory has been conducting high quality subjective evaluations of audio and speech technology for more than 27 years. Again, Dynastat's laboratory was open to the NRSC, and an NRSC observer validated the procedures used at Dynastat. Appendix G contains a thorough explanation of the rationale for the subjective evaluation program and an overview of the procedures used for selection and handling of the audio samples subjectively evaluated. Appendix H contains a detailed description of the methodology and specific procedures used at Dynastat. Appendix I details the results of the subjective evaluation.

Field testing comprised the final component of the test program. The NRSC's field test procedures identified specific conditions to be tested, the test stations to be used and the drive routes to be followed. These field tests were conducted at several commercial and one experimental FM radio station. All tests were conducted using iBiquity personnel and equipment. The majority of the field tests were conducted in the presence of an independent auditor supplied by the ATTC. An NRSC observer witnessed all field tests. Appendix E contains a detailed description of the field test equipment, the set up in the mobile van used to record measurements and the overall parameters of the field testing. The field test stations are listed below.

Station	Location	Frequency	Class	Analog Power	Digital Power	HAAT
WETA	Washington, DC	90.9 MHz	B	75kW	750W	185m
WHFS	Annapolis, MD	99.1 MHz	B	50kW	500W	142m
WPOC	Baltimore, MD	93.1 MHz	B	16kW	160W	269m
WNEW	New York, NY	102.7 MHz	B	6kW	60W	413m
WWIN	Baltimore, MD	95.9 MHz	A	3kW	30W	95m
KWNR	Las Vegas, NV	95.5 MHz	C	92kW	920W	351m
KLLC	San Francisco, CA	97.3 MHz	B	82kW	820W	315m
WD2XAB	Columbia, MD	93.5 MHz	N/A	800W	8W	15m

Table 2 - Field Test Stations

Appendix F contains the objective field test results in the form of maps and charts. For each test station, iBiquity has supplied a map depicting the digital coverage on all radials driven, a map of the digital coverage plotted against the Longley-Rice predicted signal level for the station,¹ and strip charts for each radial. The strip charts contain additional details about the strength of adjacent channel interferers, distance from the transmitter and whether the digital receiver was operating in digital or analog mode. In addition, Appendix F contains terrain elevation information for each test station.

Audio samples from the field tests were selected for further evaluation based on the NRSC's criteria for characteristics to be assessed from the field tests. These audio samples were sent to Dynastat for subjective evaluation and were used as the basis for

¹ Because WD2XAB is not a commercial station, no predicted coverage map has been included for this station.

developing Mean Opinion Scores for digital performance and for an additional test of durability (“Ticker” Test) described in Appendix K. An NRSC observer inspected the methodology and procedures and set up for selection of audio samples from the field tests and certified that the process conformed to the NRSC’s standards.

C. Subjective Component of NRSC Test Program

There are numerous ways to measure and characterize audio system performance, including objective measurement, subjective evaluation and expert listener assessment. It is widely accepted that subjective assessment plays a critical role in effectively characterizing transmission devices, audio compression, codecs and other non-linear DSP based techniques.² For the last fifteen years, subjective evaluation has been considered “the gold standard of audio system evaluation”³ in both the telecommunications and audio industries. As is evident from a vast number of ITU-R standards,⁴ the audio and codec communities have embraced methodologies that rely on subjective evaluation to assess the audio quality of new products. Thus, although the objective results from the laboratory and field tests provide interesting data, iBiquity believes that subjective evaluation results provide the best means to assess the true significance of a system’s performance. In particular, subjective evaluation using general population participants allows the NRSC to understand customer acceptance of IBOC in a variety of real-world listening conditions. This should provide the best insight into the value of IBOC as an upgrade to analog radio as well as the most meaningful assessment of whether IBOC will have a meaningful impact on existing analog operations.

In order to subjectively assess the audio quality of a system it is critical to choose a test methodology that predicts real-world behavior of consumers in real-world environments. When the experimental task closely matches the experience that people will actually encounter, the experiment will inevitably produce the most accurate prediction of customer acceptability. With this in mind, the NRSC approved a large-scale subjective test program for the purpose of evaluating the IBOC system. Subjective experiments were conducted for all major areas included in the NRSC test plan, including hybrid performance, compatibility, main channel and subcarrier transmissions. iBiquity developed an additional experiment to assess durability in core coverage areas (Ticker Test), and an experiment was conducted to help interpret results from the subjective evaluations (Interpretation of MOS, found in Appendix J). Approximately 480 people

² Thorpe, L.A. & Shelton, B. R. (1993) Subjective Test Methodology: MOS vs DMOS in Evaluation of Speech Coding Algorithms. Proceedings of the IEEE Speech Coding Workshop, St. Agathe, Quebec, Sept. 1993; Thorpe, L.A. (2000) Subjective Evaluation of Speech Compression Codecs and other Non-linear Voice-path Devices for Telephony Applications (ms. under review).

³ Pickholtz, R. L., Jackson, C. L. (1999) A Review of Four Studies of FM Receiver Adjacent-Channel Immunity (review submitted to the NAB).

⁴ Methods for the Subjective Assessment of Small Impairments in Audio Systems Including Multichannel Sound Systems, ITU-R Recommendation BS.1116, Geneva; Subjective Assessment of Sound Quality, ITU-R Recommendation 562-3, Geneva; Methods for the Subjective Assessment of Sound Quality, ITU-R BS.1284, Geneva; Methods for Subjective Determination of Transmission Quality, ITU-T P.800, Geneva.

with diverse demographic backgrounds participated in the subjective evaluation program. Results from each experiment represent data from 40 participants, stratified by both gender and age.

The chosen subjective test methodology, the Absolute Category Rating Mean Opinion Score (ACRM), has been used in a variety of circumstances to test customer opinion of telecommunications and audio products entering the marketplace.⁵ This methodology was chosen because it best tests customer preference and market acceptability. In the ACR methodology, subjects judge the sound samples they hear on an individual basis. For each sample, they use their internal frame of reference to judge the audio quality. Participants subjectively evaluate audio samples based on five categories: Excellent; Good; Fair; Poor; Bad. Answers from the participants are later translated into numerical values (5 through 1) for the purpose of computing mean opinion scores from individual scores. In each ACR experiment, participants were presented with approximately 200 sound samples that differed on several dimensions. They were asked to give a statement of “overall quality” for each sample, taking into consideration the variety of audio dimensions or impairments that were present. Before starting the experiment, participants were familiarized with the range of impairments they would encounter. The subjective evaluation lab screened participants for their ability to hear small impairments and/or differences in audio quality. Only responses from participants who were trained and who passed the screening test were included in the data that is presented in this report.⁶

The MOS Interpretation Study was conducted for the purpose of providing context for scores derived from ACR experiments. This study identified the point at which an average listener would no longer listen to a radio signal. This point was slightly different for each genre: 2.0 for Rock; 2.1 for Classical Music, and a 2.3 for speech. When interpreting subjective evaluation results this average “turn’ off” point should be considered as one measure of consumer acceptability.

D. Value of Field Test Results

A review of the laboratory and field test results reveals that field tests are much more predictive of actual IBOC system performance than laboratory test results. For a variety of reasons, the laboratory tests were limited by the constraints of the laboratory environment and provided inaccurate reflections of the performance of both analog and digital audio broadcasting.

As is apparent in this test program, in both the performance and compatibility tests, the lab exaggerated the most extreme results. In the performance tests, this produced unrealistically low evaluations of analog quality. Table 3 below shows two examples of this effect, taken from performance test data. The first example,

⁵ The ACRM is documented in the ITU-T P.800 standard, Methods for Subjective Determination of Transmission Quality.

⁶ See Appendices G & H for a detailed description of ACRM.

Performance With First Adjacent Channel Interference, is the most extreme case in which field and lab data diverge. The second case, Performance With First Adjacent Channel Interference And With Multipath, is more typical. Both cases, however, demonstrate that lab tests bias results. Obviously, in these cases, the analog radios received unrealistically low scores. In compatibility tests, the opposite happens, leading to unrealistic concern about analog susceptibility to digital impact. There are several reasons why field tests are more reliable indicators of both IBOC and analog performance

	1 st Adjacent Interference		1 st Adjacent w/ Multipath	
	Field	Lab	Field	Lab
IBOC	4.5	4.6	4.3	4.0
Delphi	4.0	1.0	3.0	2.2
Pioneer	4.0	1.0	2.6	2.4

Table 3 - Example of Exaggerated Lab Test Results

than laboratory tests. First, experiments that use commercially broadcast material transmitted over actual commercial systems most closely mimics the real world. In contrast, audio generated in the laboratory environment sounds more artificial to listeners. This stems from the fact that field audio samples are more complex, mixing a range of real-world impairments into the audio segments. However, laboratory samples are created by mixing one or more specific impairments with a clean channel signal. The result is often a laboratory sample that overly emphasizes the impairment. The most obvious example of this is in the area of multipath. Second, field tests offer a wider range of test conditions (more critical D/U ratios, larger range of programmatic material) than lab tests. Finally, a great percentage of lab tests were designed to explore extreme conditions and system limits rather than more common listening experiences. Again, these extremes apparently affected listeners' ratings negatively, as is reflected in the harsher evaluations they gave to both analog and digital systems at various points in the laboratory program.

E. The Test Report

This test report consists of a main text analyzing each of the NRSC evaluation criteria and the iBiquity system's ability to satisfy each of the criteria. In addition, the report includes a series of appendices, which contain greater detail about the system design, the test procedures and methodology, and the test results. iBiquity completed 100% of the tests outlined in both the laboratory and field test procedures. iBiquity performed additional tests, such as the Ticker Test and the MOS Interpretation Test, as

well as detailed station, market and listener analyses to qualify the results presented in this report a more complete understanding of the IBOC system. This report presents (i) all the results from the laboratory and field performance tests and (ii) laboratory and field compatibility tests for main channel audio. Lab and field compatibility tests involving SCA operations will be presented at a later date.

II. Results

A. Audio Quality⁷

The performance tests, taken in their entirety, establish conclusively the superiority of the audio quality of the iBiquity system over existing analog FM. In subjective evaluations of all the performance tests, evaluators overwhelmingly and consistently scored digital superior to analog. Performance sound samples were selected from seven of the eight FM test stations providing a strong cross section of formats and conditions.⁸ These samples comprised three full tests at Dynastat and involved 120 listeners evaluating over 600 sound samples. As Figure 1 below illustrates, digital consistently outperformed analog. Figure 1 aggregates the performance of the IBOC, Delphi and Pioneer receivers in all conditions. This includes first adjacent, second adjacent and dual adjacent interference, noise, multipath and channel impairments. In each genre tested, digital was judged to be superior to analog.

⁷ The IBOC DAB equipment used in the tests incorporated the AAC audio compression technology rather than the iBiquity audio compression technology that the final system will use. The codec used in the test equipment has no impact on the NRSC's ability to assess the compatibility of the system with existing analog operations or the performance of the system in the face of impairments and interference. However, the NRSC agreed that the unimpaired audio quality test, which looks at audio fidelity in a clean channel environment, is designed to assess the performance of the codec and would be inappropriate to conduct until iBiquity's compression technology is incorporated in the system. Therefore, no data related to *unimpaired* audio quality is available from this test program.

⁸ Field testing of WWIN was completed after the performance audio samples had been sent for subjective evaluation.

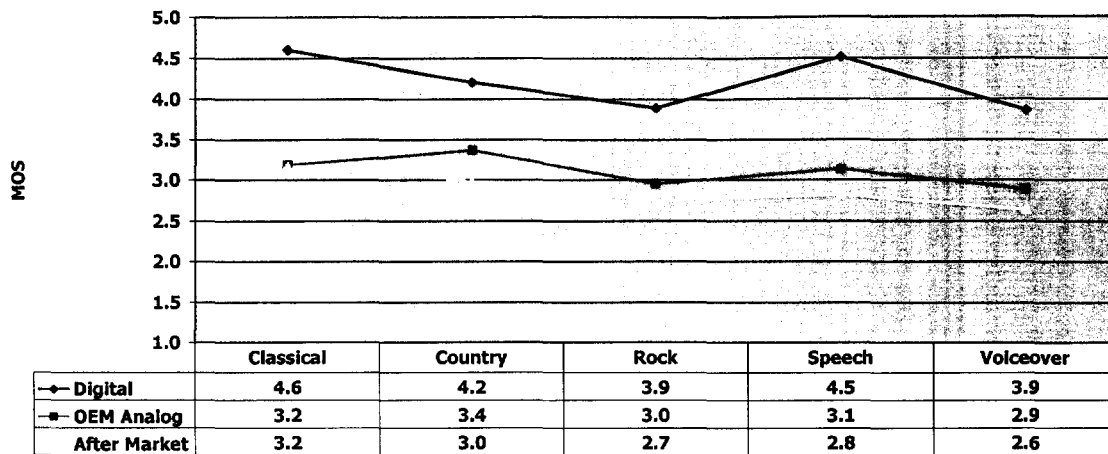


Figure 1 - Performance of Digital and Analog Receivers
Aggregating All Field Test Conditions

Although these performance tests also assessed the durability of the system, iBiquity believes that listener evaluations were based on the superior audio quality of the digital signal, the system's enhanced ability to overcome impairments and the improved quality of the overall listening experience. The first and third of these factors relate to overall audio quality. iBiquity believes these perceptions of greatly enhanced audio quality can be attributed to two benefits of the iBiquity system. IBOC is able to deliver higher audio fidelity that approaches compact-disc quality. At the same time, many of the innovative technologies incorporated in the system have been designed to reduce or eliminate the noticeable impairments that frequently degrade the listening experience of analog FM. The elimination or reduction of effects from multipath interference, the reduction in the system's susceptibility to noise and other impairments and the interference reducing techniques incorporated in the system all reduce the audible pops and clicks that have impaired the analog FM listening experience. The success of iBiquity's efforts to enhance the listening experience and improve audio quality is borne out by the subjective evaluation results.

B. Service Area

Field tests using eight stations demonstrated that the IBOC system provided an extensive digital service area in all environments typically encountered in FM broadcasting. Even at 1/100 of the power of analog, IBOC provides high quality audio throughout the existing market. Field test environments emphasized (i) first and second adjacent channel interference, (ii) severe specular and diffuse multipath, (iii) urban, suburban and rural conditions, and (iv) terrain obstructions. Field test stations included

all classes of FM stations with one Class A station, five Class B stations and one Class C station. In all cases, digital coverage extended to approximately the 45-50 dBu signal level. In several cases, digital coverage extended well beyond this point to the 15-25 dBu signal level. Although the differing characteristics of the field test stations make it difficult to generalize about the digital service area, the results indicate the IBOC system offers digital coverage meeting or exceeding each station's protected analog coverage area. In all cases, the system's blend-to-analog feature ensures that coverage was never less than existing analog coverage.

The field test stations incorporated in the NRSC test procedures were selected to assess system performance in the most common FM environments. Table 4 below contains a list of the relevant broadcast environments included in the field test program and which stations were used to assess each environment

Characteristic Assessed	Station
1. Overall Coverage -- Performance in an area characterized by low interference	WETA
2. 1 st Adjacent Channel Interference	WPOC, WNEW
3. 2 nd Adjacent Analog Interference	WNEW, KLLC
4. 2 nd Adjacent Digital Interference	WD2XAB
5. Dual 2 nd Adjacent Channel Analog Interference	WHFS
6. Multipath	WNEW, KLLC, KWNR, WHFS
7. Class A Facility	WWIN
8. Centrally Located Urban Antenna	WNEW
9. Terrain Obstructions	KLLC, KWNR
10. Low Level Power Combining	WWIN

Table 4 - Field Test Stations and Characteristics Assessed During Tests

1. Overall Coverage

WETA provides one of the best examples of the overall coverage of the digital system. WETA has no strong first or second adjacent channel interferer and does not have significant terrain obstructions, except in the western part of its service area. Because WETA is located in a congested, urban market, multipath interference impacts coverage and service quality for analog reception. Even so, with an antenna height of 186 meters HAAT and analog power of 75 kW, WETA enjoys extensive analog coverage. The field performance tests demonstrate extensive *digital* coverage on WETA as well. As Figure 2 illustrates, on all radials, the system delivered consistent digital coverage to approximately the 35 dBu signal level.

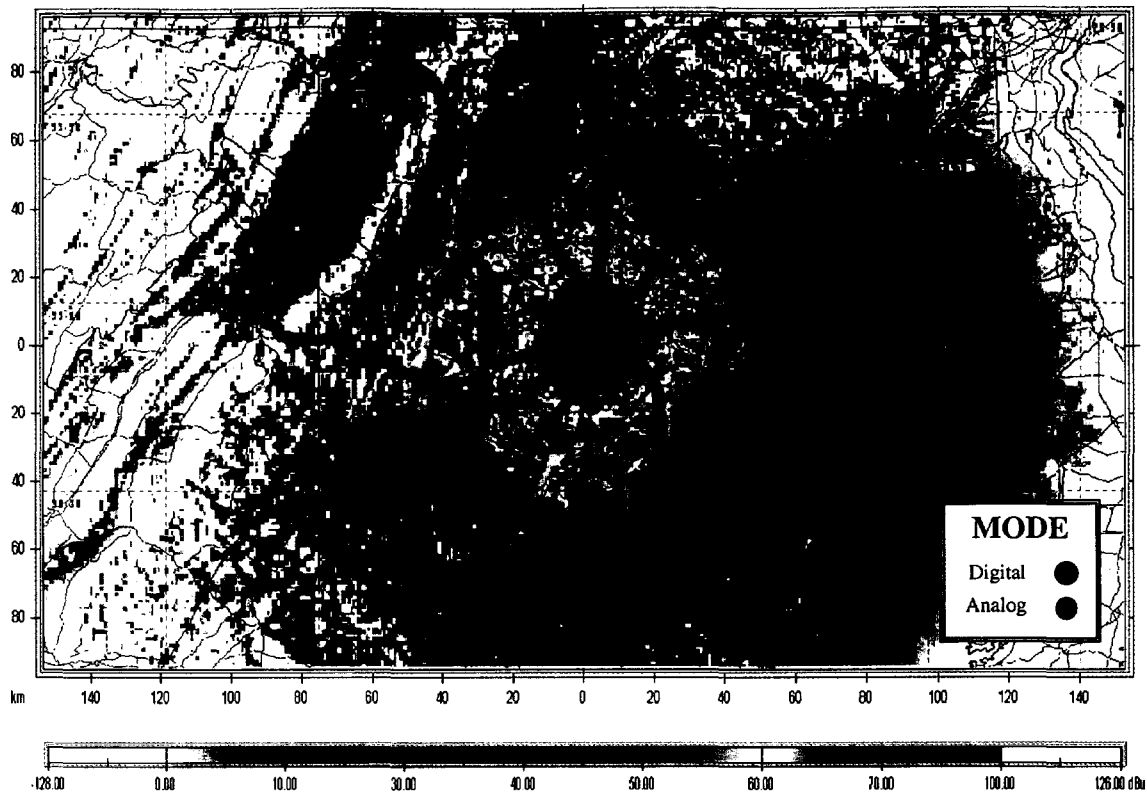


Figure 2 -WETA All Radials with Analog Field Intensity

A more detailed analysis of the western radials for WETA reinforces the conclusion that WETA has extensive digital coverage. Figure 3 provides a more detailed presentation of the WETA analog field intensity for the 270° and 315° radials. As Figure 3 highlights, the first blends on these radials occurred at approximately 35 dBu. However, even after the initial blends, digital reception continued into areas of 5-10 dBu signal level. In both these cases, this impressive digital coverage occurred even after terrain related blockages caused initial blends to analog. It is important to note analog quality is degraded at the points where digital blends.⁹

⁹ See Appendix F.1, page 11 for an illustration of the terrain elevations on these radials.

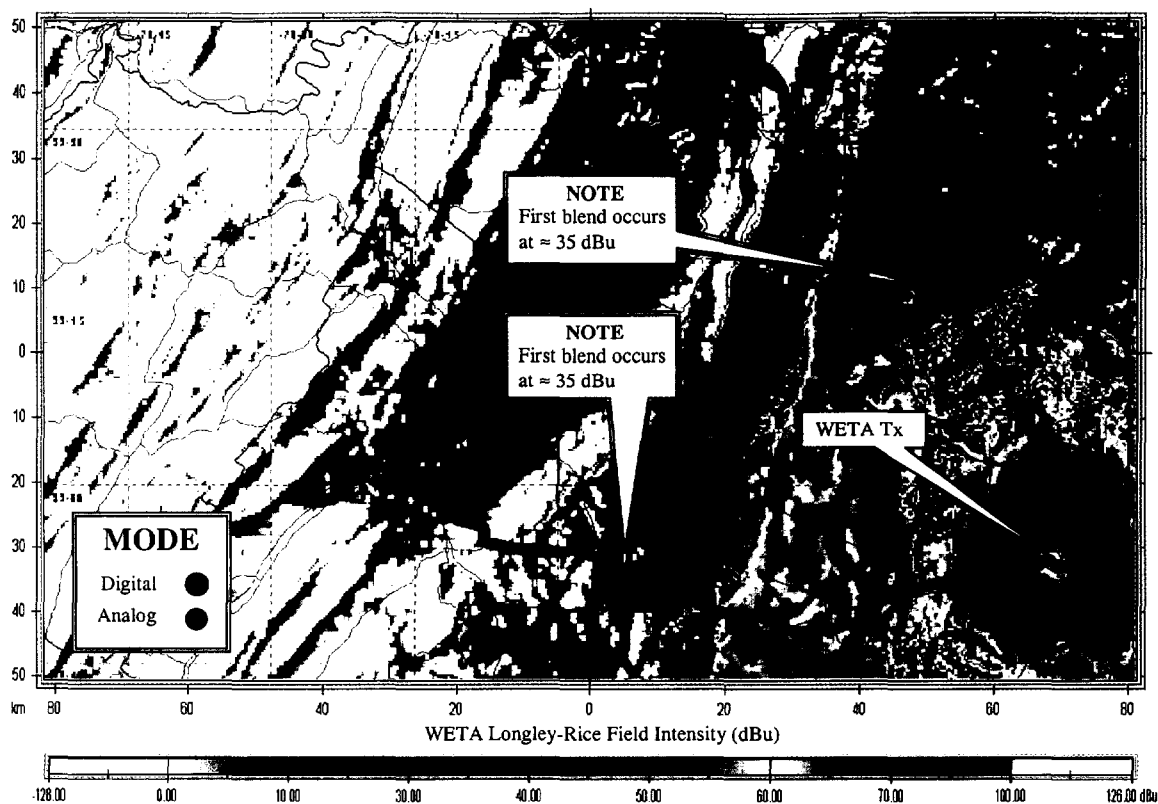


Figure 3 -WETA 270° and 315° Radial with Analog Field Intensity

Although many other stations experience greater limitations on their analog coverage due to significant interference or other impairments, iBiquity believes the WETA coverage illustrates the potential for extensive digital coverage on the numerous analog stations which currently enjoy large analog coverage.

2. Coverage with First Adjacent Channel Analog Interference

Tests conducted on both WPOC and WNEW demonstrated first adjacent channel interference did not impact digital coverage. Both stations have first adjacent interferers that were assessed in the field test program. Table 5 below lists the adjacent channel interferers for each station.

Desired Station				Interferer				
Call Sign	Location	Channel	Class	Call Sign	Location	Channel	Class	Distance Between Stations
WPOC	Baltimore, MD	93.1	B	WFLS	Fredericks-berg, VA	93.3	B	123 km
				WMMR	Philadelphia, PA	93.3	B	155 km
WNEW	New York, NY	102.7	B	WMGK	Philadelphia, PA	102.9	B	132 km

Table 5 - First Adjacent Interferers

In both cases, the digital coverage was consistent and extensive. Even in the presence of first adjacent channel interference, digital coverage for each station extended to the 35-38 dBu signal level.¹⁰

3. Coverage with Second Adjacent Channel Analog Interference

Tests conducted using WNEW demonstrated the strength of digital coverage even in the presence of strong second adjacent channel analog interference. WNEW has a lower second adjacent channel station, WBAB-FM, operating at 102.3 MHz in Babylon, New York. Figure 4 below illustrates the WNEW 90° radial plotted against the WBAB differential field intensity. This shows the D/U ratio for WBAB's interference to WNEW. As can be seen in Figure 4, the 90° radial for WNEW passed directly by the WBAB transmitter. Nonetheless, the system continued to deliver digital coverage. Figure 4 shows that digital coverage extended to the 100 dBu contour for WBAB. At that point, the system was experiencing a D/U ratio of approximately -47 dB.

¹⁰ See Appendix F.2 at page 1 for more details on the WPOC service area and Appendix F.4 at page 1 for more details on the WNEW service area.

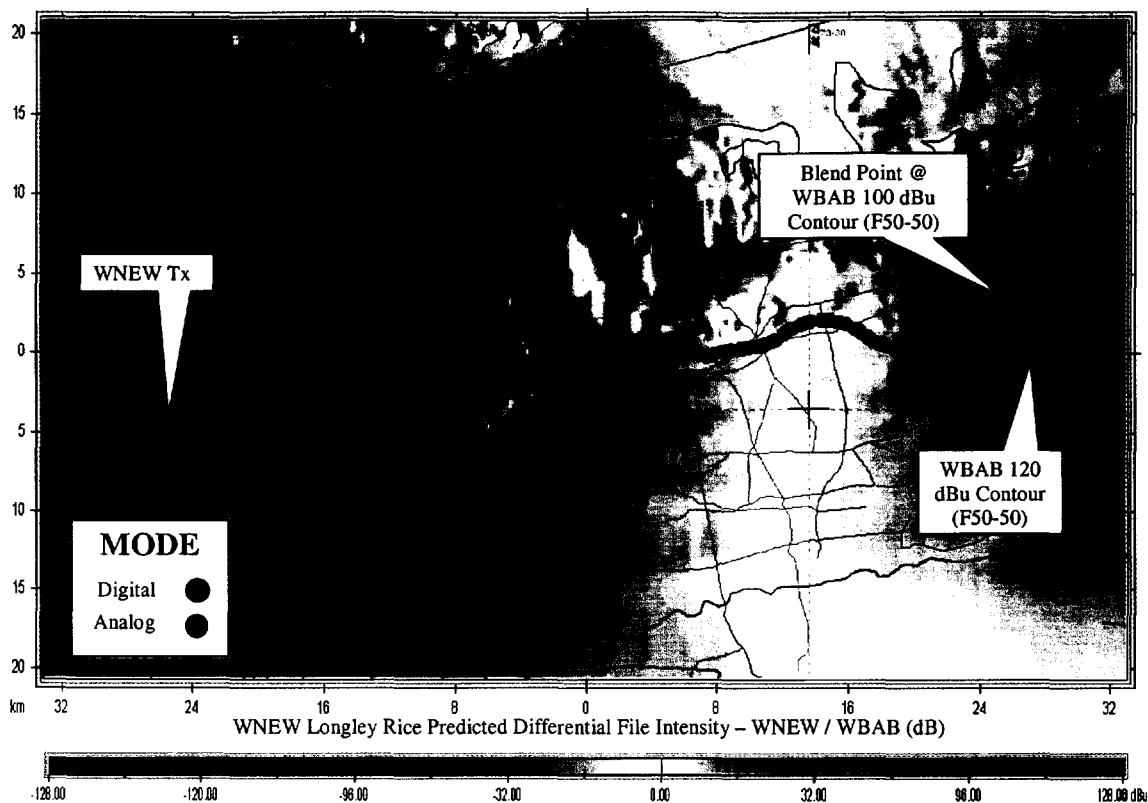


Figure 4 – WNEW 90° Radial with WBAB Field Intensity

iBiquity does not expect that all second adjacent channel interference levels will reach this extreme. Nonetheless, this radial was selected to demonstrate the extensive service offerings made possible by the IBOC system even with the existence of very severe levels of second adjacent channel interference.

Similar results were obtained with second adjacent channel interference in the San Francisco market. On the South Loop for KLLC, the radial passed within a few kilometers of the KFFG-FM transmitter. KFFG is an upper second adjacent channel interferer operating at 97.7 MHz. Figure 5 shows the IBOC coverage plotted against the D/U ratios for KFFG's interference to KLLC. As Figure 5 illustrates, the IBOC system offered primarily digital coverage within the 80 dBu contour of KFFG.

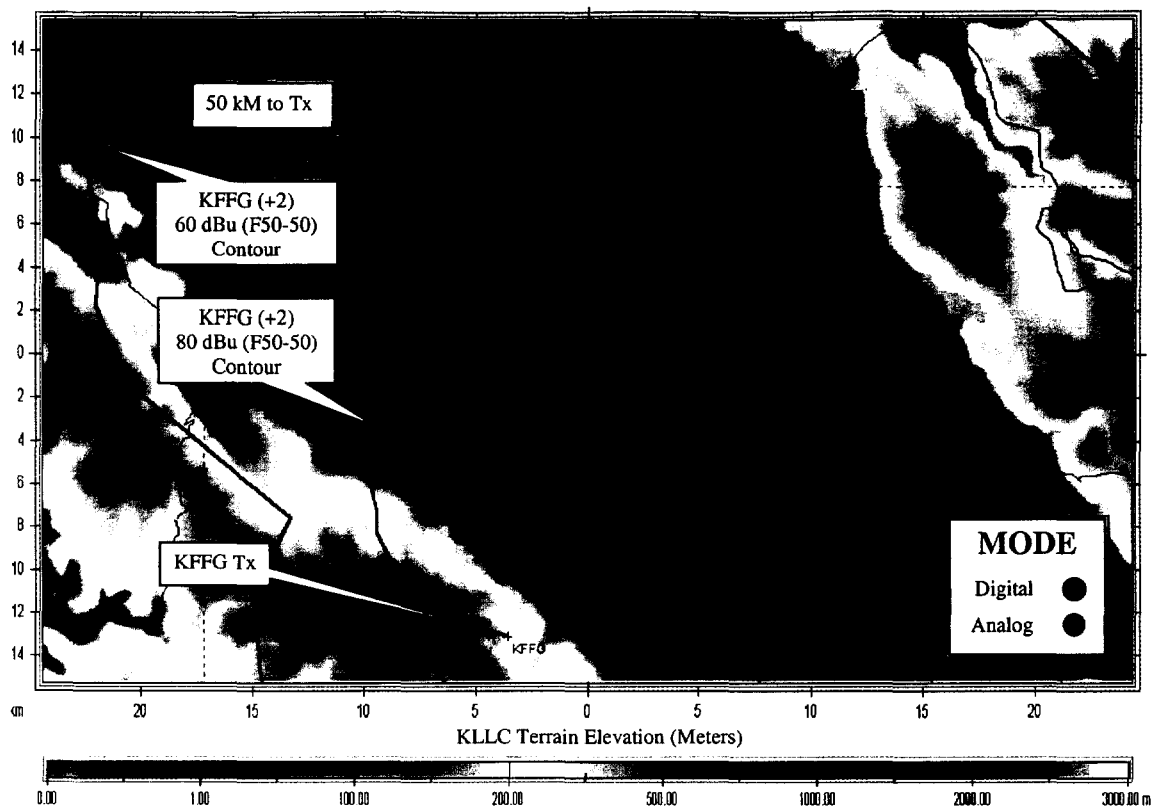


Figure 5 - KLLC South Loop with KFFG Field Intensity

4. Coverage with Second Adjacent Channel Digital Interference

WD2XAB was used to demonstrate the IBOC system's ability to maintain digital coverage with second adjacent channel digital interference. WD2XAB operates at 93.5 MHz, second adjacent to WPOC at 93.1 MHz. For these tests, WD2XAB operated in the hybrid mode at the same time that WPOC was broadcasting a hybrid signal. Because WD2XAB is an experimental station operating at limited power of 800 Watts, its analog coverage is extremely limited. Nonetheless, the tests demonstrated the system's ability to deliver digital coverage even with high levels of second adjacent channel digital interference. The test results demonstrate the station was able to provide extensive digital coverage to approximately the -15 dB D/U signal ratio.¹¹

5. Coverage with Dual Second Adjacent Channel Analog Interferers

Field tests conducted using WHFS confirmed the system's ability to withstand strong levels of dual second adjacent channel interference and still deliver digital coverage. WHFS, located in Annapolis, Maryland and operating at 99.1 MHz, has two second adjacent channel interferers operating in the same market. WIHT-FM,

¹¹ See Appendix F.8 for additional details about tests on this station.

Washington, D.C., is an upper second adjacent operating at 99.5 MHz. WMZQ-FM, Washington, D.C., is a lower second adjacent operating at 98.7 MHz. Both second adjacent interferers are located at the western edge of WHFS' analog coverage area.

A detailed examination of the 270° radial illustrates the significant coverage of the digital system. This radial passes within less than 1 km of the transmitter for WMZQ. Even so, the system exhibits only limited blending throughout this area. Significant blends do not occur until past the WMZQ transmitter site where the radial reaches beyond the edge of digital coverage. Figure 6 shows the radial plotted against the WMZQ interference to WHFS. As Figure 6 illustrates, even within the 120 dBu contour of WMZQ, which is approximately 49 km from the WHFS transmitter, WHFS still delivered partial digital coverage. That means the IBOC system was able to perform even with interference levels of -65 dBu D/U.

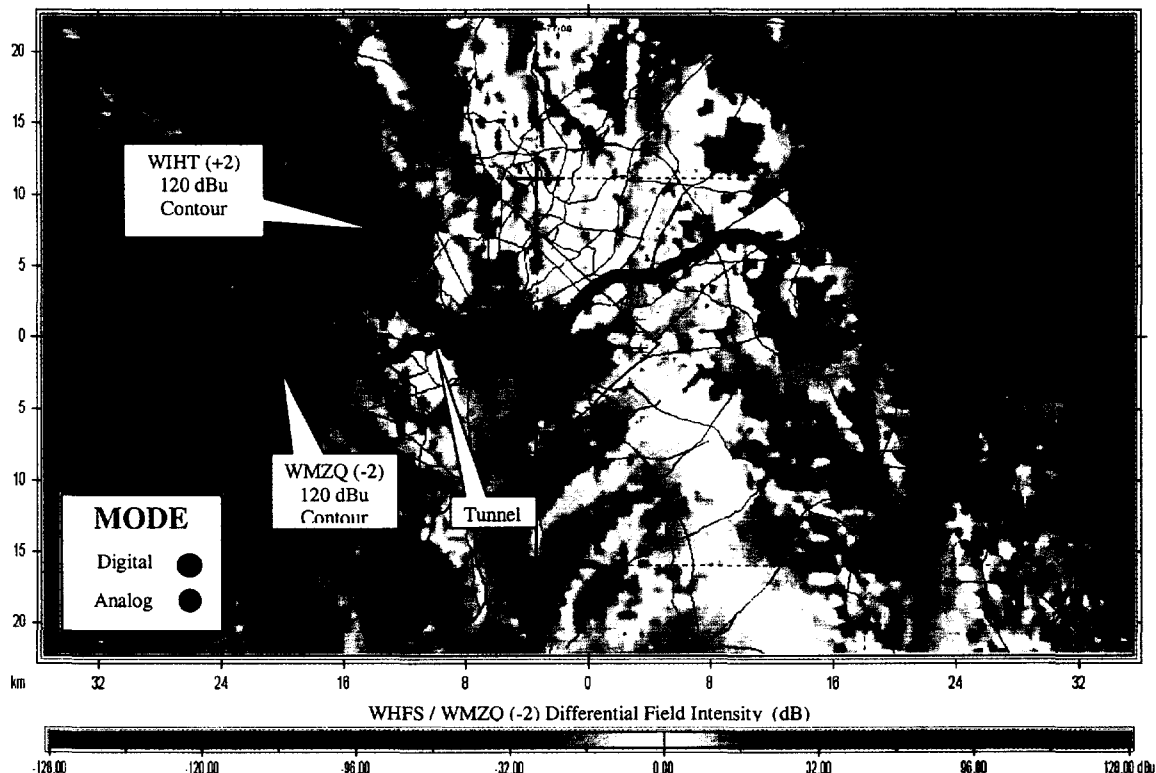


Figure 6 – WHFS 270° Radial with WMZQ Predicted Analog Interference

Figure 7 highlights the loss of digital that occurs in this area. In the majority of cases, digital is lost due to front end overload caused by close proximity to the WMZQ transmitter. At this interference level, the undesired signal saturates the receiver front end eliminating reception of the desired signal. Analog radios experience the same effect in these situations.

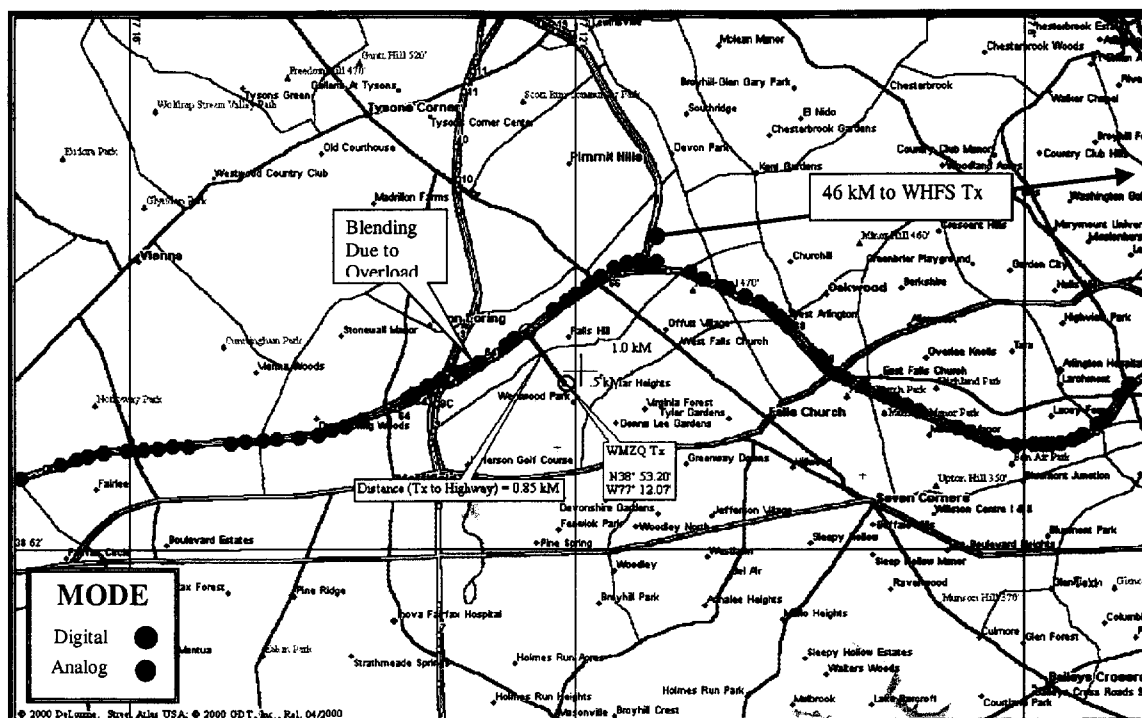


Figure 7 – WHFS 270° Radial Selection Adjacent to WMZQ Transmitter

This location illustrates one of the most extreme cases of second adjacent interference due to the distance from the WHFS transmitter and the proximity to the second adjacent interferer. Nonetheless, the digital system delivers exceptional performance.

6. Coverage with Multipath

Throughout the test program, the digital system provided an outstanding coverage area even in markets characterized by severe multipath. KWNR in Las Vegas, Nevada is located in a market dominated by severe specular multipath. The geography of Las Vegas, situated in a bowl surrounded by mountains, encourages the reflection of FM signals. Even with this severe multipath situation, the digital system provided excellent coverage of the Las Vegas market. In fact, the KWNR results show that terrain, not multipath, set the limit on digital coverage. The Las Vegas tests also included a downtown radial on “The Strip” to maximize the potential for multipath interference. As Figure 8 below illustrates, there was uniform digital coverage throughout this drive.

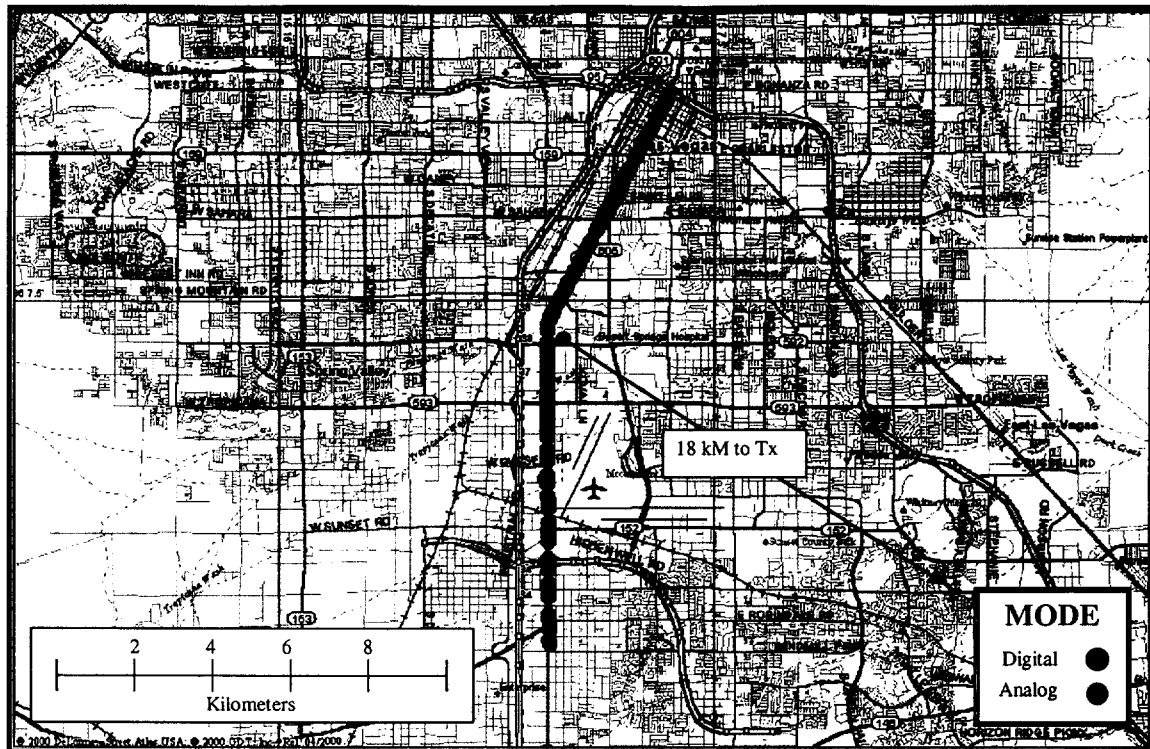


Figure 8 – KWNR “Strip” Radial

Similar results were obtained in urban markets characterized by specular multipath. In New York, WNEW coverage was uninterrupted by the high levels of multipath typical of Manhattan’s urban canyons. This outstanding digital coverage was obtained in an area well known for severely degraded analog reception. The New York Downtown Loop included lower Manhattan, midtown, and upper Manhattan. This loop has a range of urban conditions including lower Manhattan’s narrow streets lined with skyscrapers, midtown’s wider streets surrounded by dense development and upper Manhattan’s mid-rise development. Figure 9 below shows the absence of blend throughout the loop except for one blend related to a tunnel.

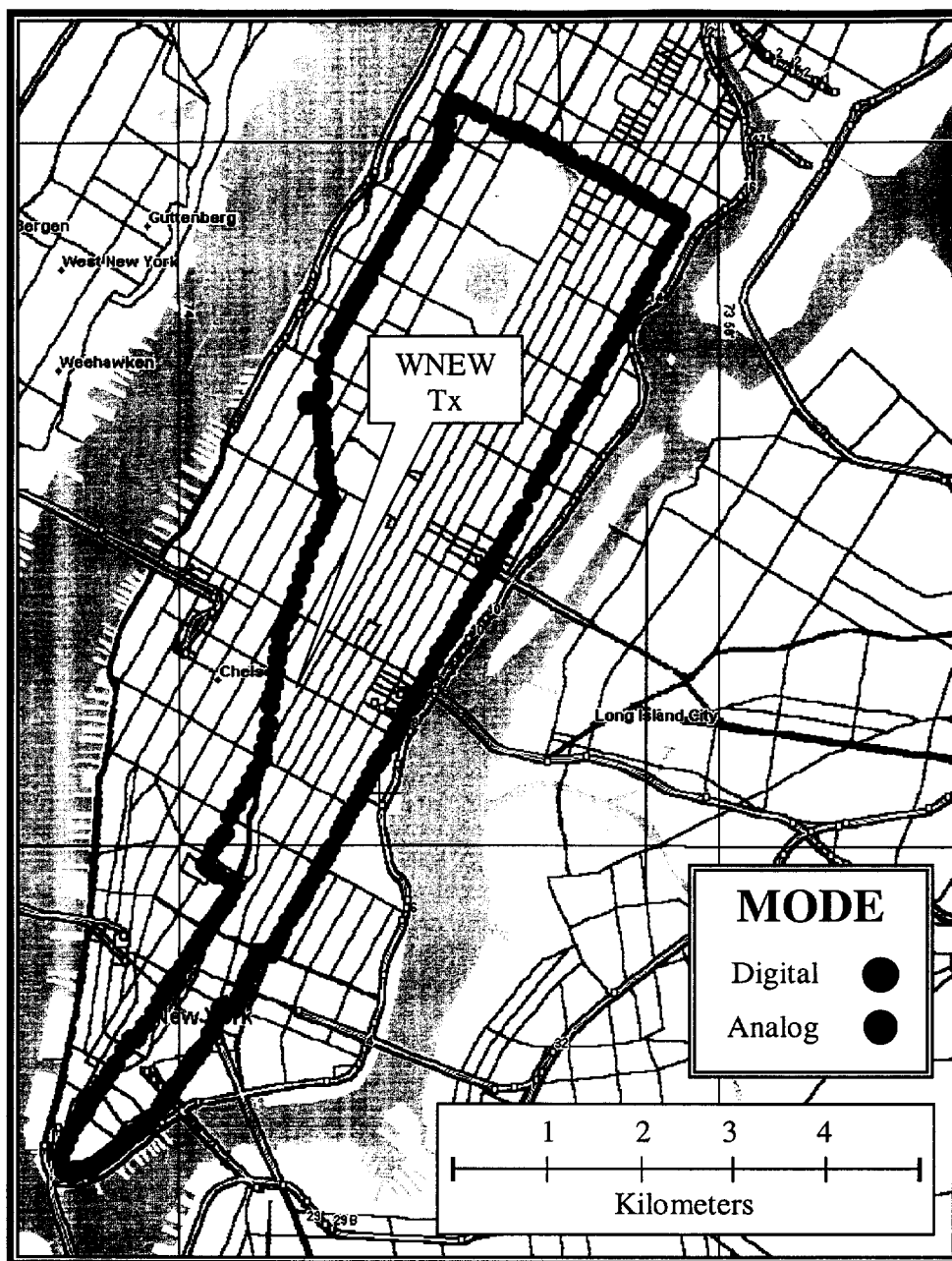


Figure 9 – WNEW Downtown Loop Street Map

Thus, the existence of extreme levels of urban multipath did not impact system performance.

Similar results were obtained on KLLC in San Francisco during the KLLC downtown loops. In that case, the system offered consistent digital coverage throughout the downtown area. The gaps between gray areas do not represent loss of digital coverage. These gaps are the result of the sampling rate of the system that records the

relevant data. At this level of resolution, the digital plots do not cover all areas of the map. The blends that are illustrated in Figure 10 were the result of receiver overload in the area close to the Mt. Sutro transmitter site. Analog reception also is severely degraded in these areas.

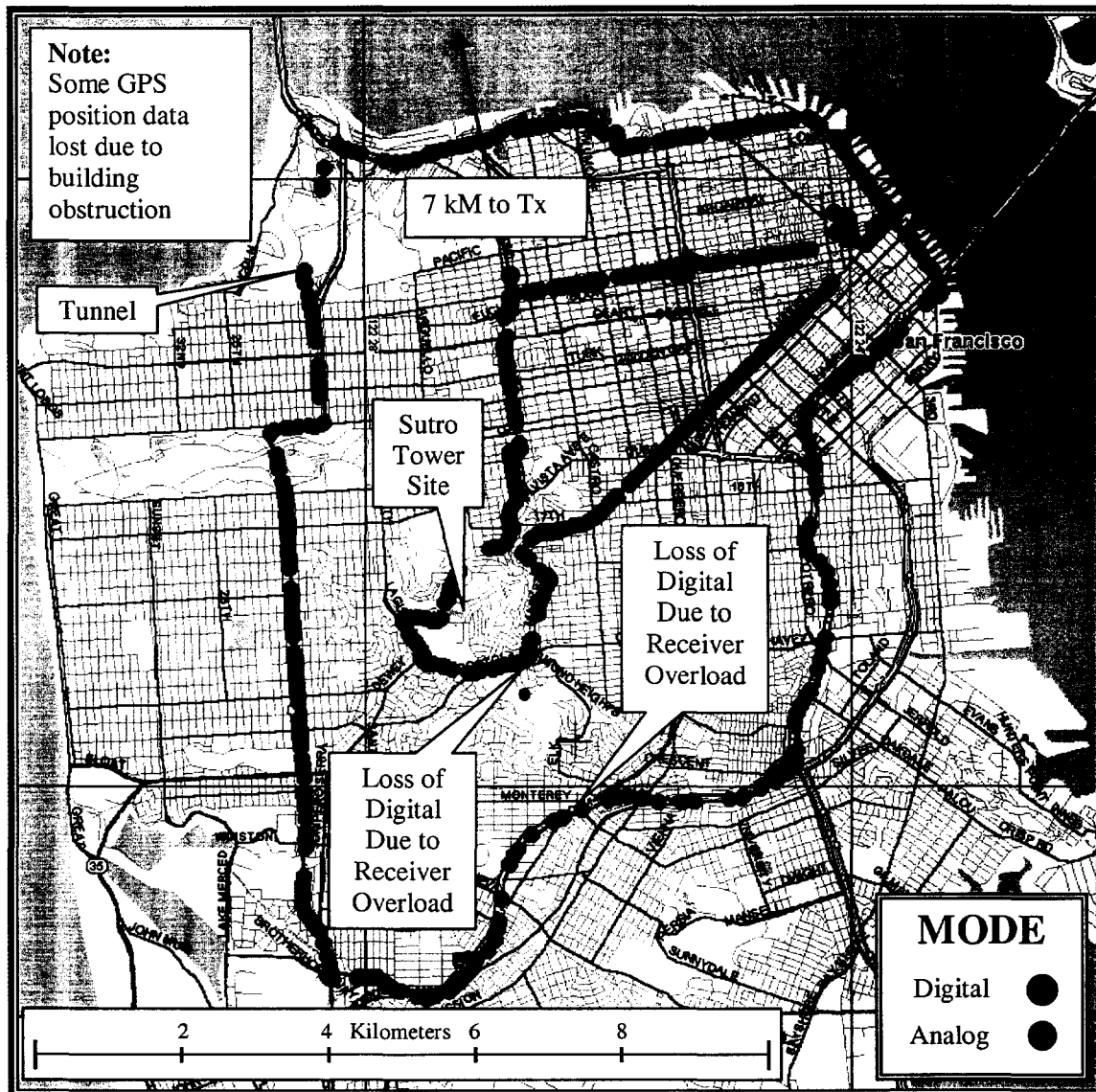


Figure 10 - KLLC Inner and Outer Downtown Loops

In the case of WNEW and KLLC, each station's transmitter was located at a high height in the urban area being studied. WHFS provided an opportunity to study the digital coverage in the face of urban multipath when the transmission originates from a distant, suburban location. The WHFS transmitter is located outside Annapolis, Maryland in an area roughly equidistant from Washington and Baltimore. On the 270° radial, the test route passed through downtown Washington. As Figure 11 illustrates,

even though the downtown areas were 30+ km from the WHFS transmitter, the digital system was able to provide consistent digital coverage of the area.

Overall these tests demonstrate the IBOC system can provide significant digital service in the presence of multipath with a variety of transmission and antenna configurations.

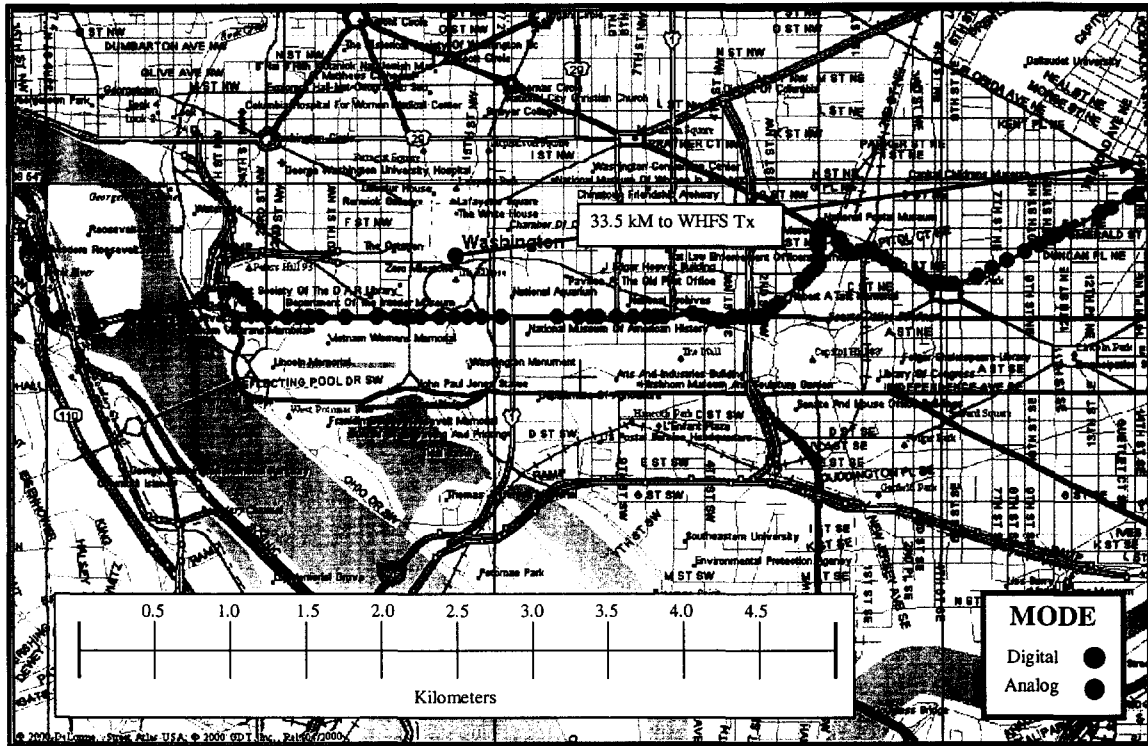


Figure 11 - WHFS 270° Radial Through Downtown Washington

7. Coverage for a Class A Facility

As with the higher powered stations, the IBOC system provided extensive coverage for a Class A facility, meeting the protected contour for WWIN. This station presented particularly challenging conditions for testing IBOC performance and may not be representative of typical Class A results. First, the WWIN tower is located at sea level at the edge of Baltimore harbor but the bulk of the service area is at a much higher elevation. Due to the station's low analog power, the IBOC system is producing only 30 watts of digital energy. Also, WWIN's service area is completely overlaid by WHUR-FM and WPGC-FM, two second adjacent channel interferers transmitting from Washington, D.C. Also, WSOX-FM, Red Lion, Pennsylvania, is a strong first adjacent interferer with significant overlap of WWIN's service area. Figure 12 below illustrates the interference environment for WWIN.

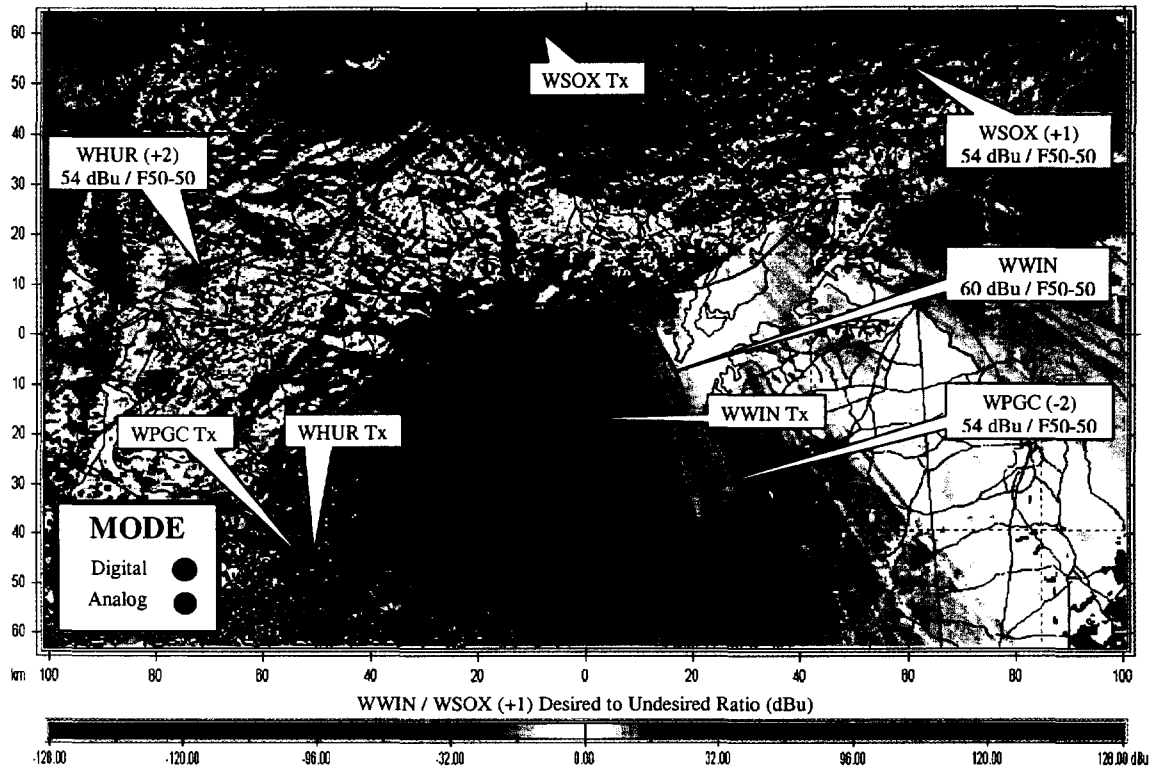


Figure 12 – WWIN Radials with First and Second Adjacent Interferers

Even with significant interference, extremely low power, and lower elevation, the digital system provided significant digital coverage. iBiquity believes more extensive coverage may be found in Class A stations with less severe interference situations.

8. Coverage with Multiple Antenna Configurations

The field tests demonstrated the IBOC system's ability to offer extensive service areas using all commonly employed FM antenna configurations. On WNEW, the digital system operated with a centrally located multiplexed antenna that carries most of New York's major FM stations. WWIN offered the opportunity to demonstrate the system's operation with common amplification whereby both the analog and digital signals were amplified by the same device. WPOC uses a stand-alone directional antenna with a null to minimize the signal level in the Washington, D.C. market. In the other cases, the system operated with stations using stand-alone antennas. It is also important to note that the test program included stations with varying antenna heights and power combinations. WHFS, which holds a conventional Class B authorization, operates at near the authorized height and full authorized power. In contrast, WNEW, also a Class B station, operates at significantly reduced power due to the height of its antenna on the Empire State Building. In all cases, the digital system offered extensive digital coverage and no compatibility issues with the various antenna configurations.

9. Coverage with Terrain Obstructions

Even with terrain obstructions, the IBOC system is able to provide digital coverage comparable to analog coverage. Although terrain elevation challenges can be found in most of the field test markets, San Francisco and Las Vegas presented some of the greatest challenges for digital coverage. Nonetheless, the IBOC coverage for both KLLC and KWNR was comparable to analog coverage.

The San Francisco market represents one of the most challenging environments for FM reception. The complete set of loops run on KLLC provides the most comprehensive overview of the system's extensive service area in a market characterized by extremes of multipath terrain obstructions. The iBiquity system was able to provide service throughout the bay area, extending to both the northern and southern ends of the bay as well as the mountains east of San Francisco. On the north loop, the system operated without any blends. As was discussed above, even though there were blends on the south loop, this actually highlights the system's ability to withstand extreme second adjacent interference from KFFG-FM. The two areas of significant blends-to-analog appear in the east and west loops. In both cases, the system provides extensive coverage except in those areas with very severe and direct terrain blockage. In those cases, the terrain also significantly impacts analog reception.

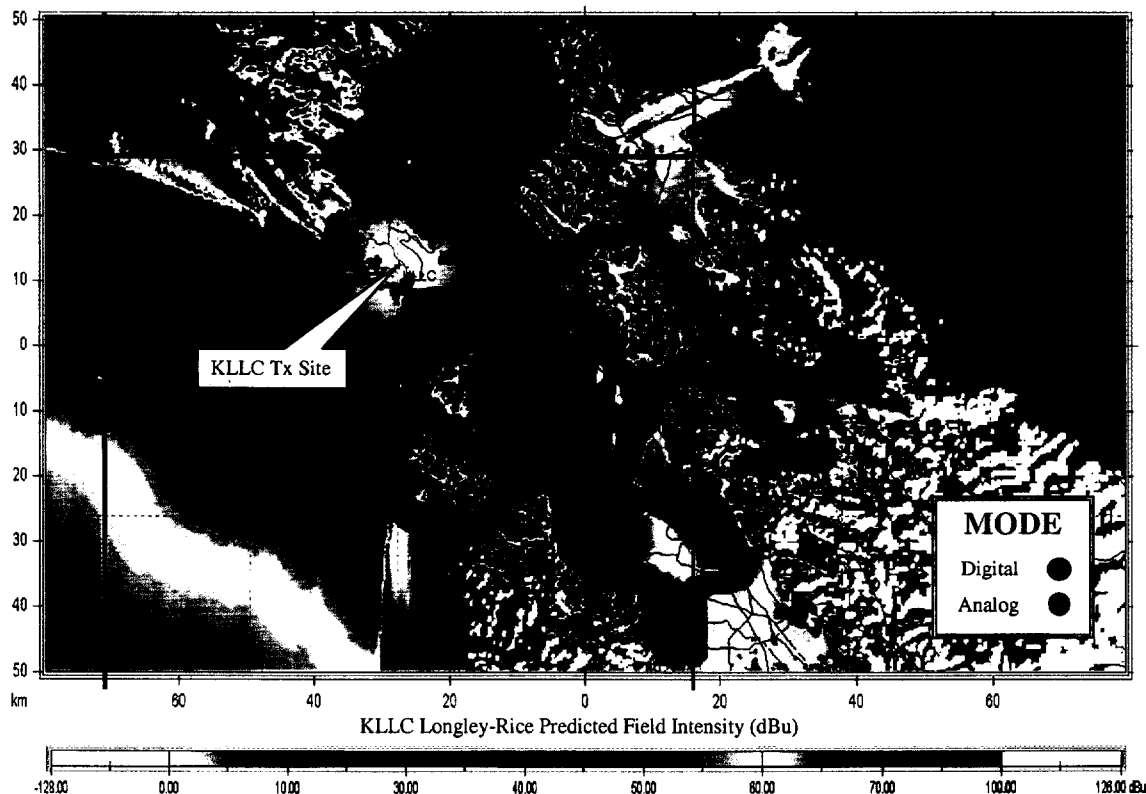


Figure 13 – KLLC All Radials with Analog Field Intensity

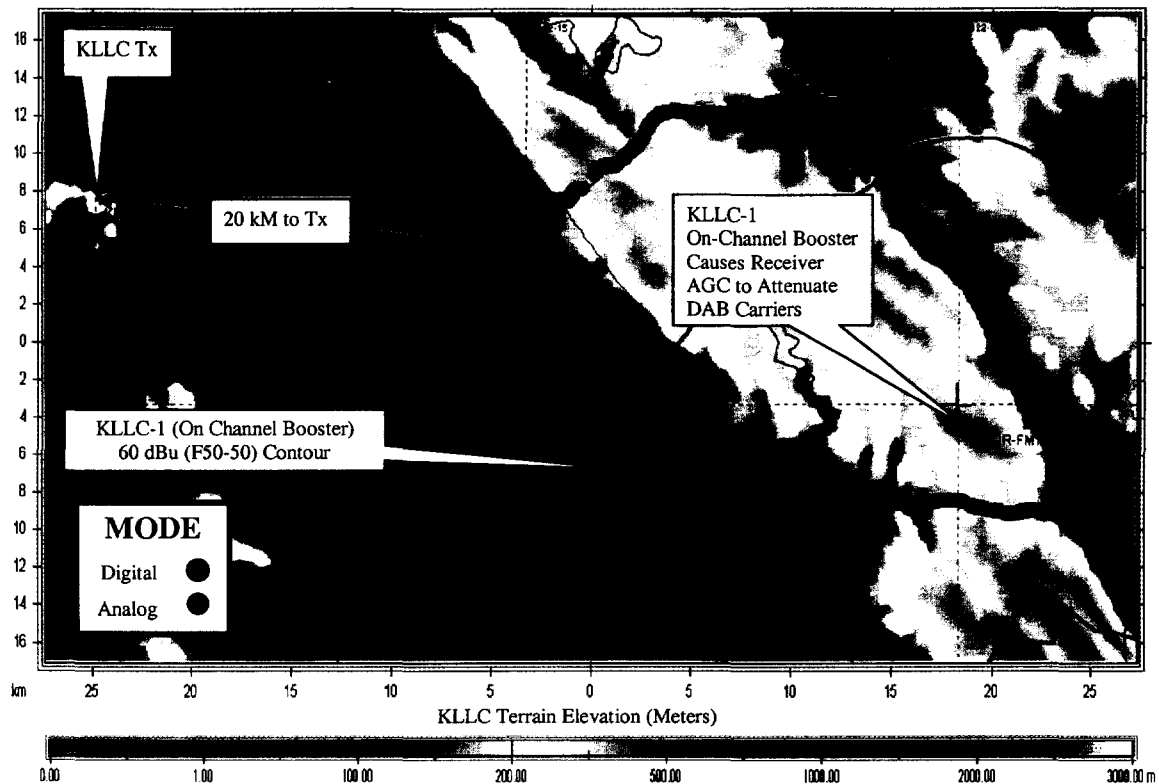


Figure 14 - KLLC East Loop Terrain Elevation

The terrain blockages are a limiting factor in the reception of analog FM signals in the San Francisco market. Mountains block the FM signals from San Francisco's three main FM transmission facilities.¹² The mountains located to the east of San Francisco Bay effectively limit FM reception from reaching the eastern and western ends of the market, except for those stations with on-channel boosters. Figure 14 illustrates the terrain limitations and shows the location and coverage of the KLLC booster, KLLC-1. Those areas of blended analog service shown in Figure 14 are effectively the signal from KLLC-1. The analog booster was providing analog coverage but the IBOC system did not have the benefit of a digital booster to provide digital service in this area.

Along the west loop, shown in Figure 15, mountains severely limit analog reception however no analog boosters are employed. Thus, in this area, analog remains degraded.

With the difficult reception problems in the San Francisco Bay area IBOC brings the possibility to offer what is not possible now, seamless coverage of the market through the use of a limited number of inexpensive on-channel IBOC boosters.¹³

¹² Mt. Beacon, Mt. Sutro and Mt. Bruno

¹³ iBiquity's FM IBOC system was designed to accommodate on-channel digital boosters. IBOC technology, unlike FM on-channel boosters, can provide service without generating areas of interface.

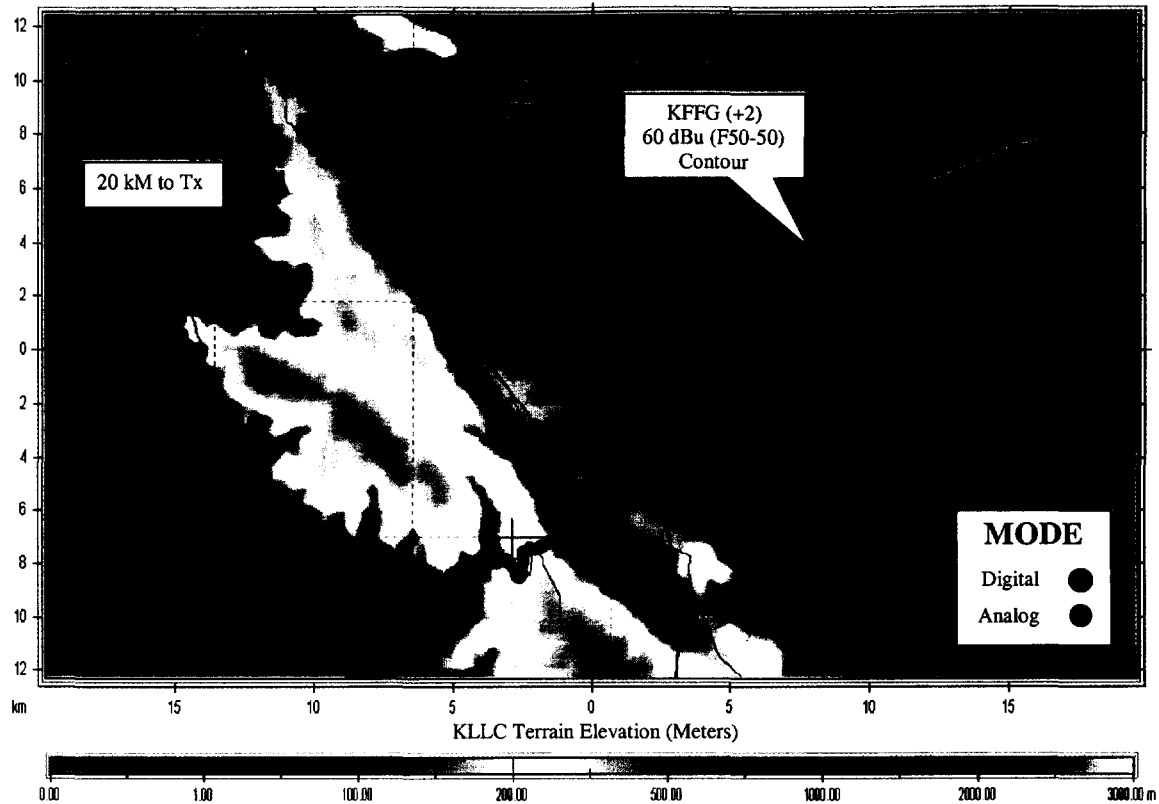


Figure 15 - KLLC West Loop Terrain Elevation

The IBOC system offered similar performance in Las Vegas. Unlike San Francisco, which has a combination of water, mountains, urban and suburban areas, Las Vegas has one urban center surrounded by a ring of mountains. As Figure 16 illustrates, the system delivered extensive coverage throughout the area, even into areas with high terrain elevation.

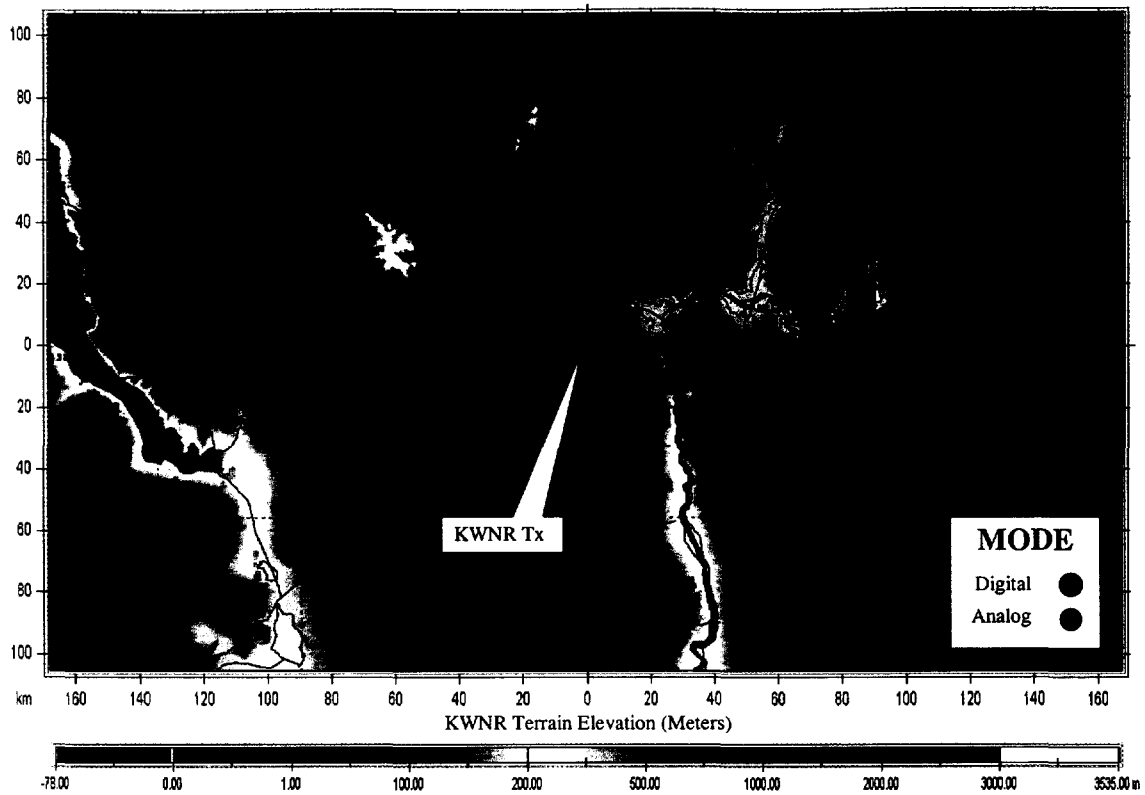


Figure 16 - KWNR All Radials with Terrain Elevation

Figure 17 highlights that the only significant blends were directly attributable to loss of signal due to terrain shielding from the mountains or the descent into the Colorado River basin at Hoover Dam. In this market, the mountains create a barrier that almost completely blocks the analog signal. In particular, there is complete muting of analog as the elevation drops down to the Hoover Dam basin. The loss of the digital signal mirrors the limitations of analog coverage in these areas.